

# **Reflections on Over Fifty Years in Research and Development; Some Lessons Learned**

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# REFLECTIONS ON 50 YEARS IN SCIENCE AND TECHNOLOGY RESEARCH

## Introduction

This paper presents some thoughts about research in science and technology (S&T) gleaned from my more than 50 years working in scientific and engineering research—first in the chemical industry, then at two different government laboratories, and later some years in S&T policy. It elaborates on a paper by Richard Chait in which he interviews three former S&T executives in the Department of Defense (DOD)<sup>1</sup> on how to manage a research laboratory. In this paper, I expand on the comments made to Dr. Chait and provide a broad context for my discussion. In addition, this paper connects a number of subjects discussed in several other papers published by the Center for Technology and National Security Policy (CTNSP). My objective is to provide some insights on what it is like to work in a scientific research establishment. My hope is that this will be of some value for the senior manager who has no laboratory experience but is responsible for overseeing a research department. I also hope the paper will help new technical personnel just entering the laboratory for the first time. For experienced laboratory staff, the paper will contain many familiar ideas and perhaps some that are controversial. Some of the paper deals with the DOD technical programs.

I include a few anecdotes, as sidebars, of unusual and memorable experiences I had in the pursuit of my duties in the laboratory. These anecdotes are intended to show the wide variation, apart from the usual bench-top research, in the sorts of things one encounters while pursuing a career in research.

I begin in Chapter 1 with a look at the various stages of research and development (R&D) and how they are connected. My focus is on the technical innovation process—moving from ideas through various stages to fielded products and processes. Chapter 2 includes a description, by way of an example, of the roles of a DOD laboratory, followed by a summary of the characteristics of a “good laboratory.” This chapter considers four kinds of research laboratories: industrial, governmental, academic, and free-standing institutes. My own experience includes industry and government laboratories. Chapter 3 compares performing all work in house to collaborating with external laboratories. Chapter 4 reviews the worldwide technical community and the various ways scientists and engineers remain informed on the latest developments in their fields. Chapter 5 presents my ideas on managing an R&D laboratory. Finally, Chapter 6 gives some advice to new members of the research community from my experience over the past half-century.

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<sup>1</sup> Richard Chait, *Perspectives From Former Executives of the DOD Corporate Research Laboratories*, Defense and Technology Paper 59 (Washington, DC: Center for Technology and National Security Policy [CTNSP], National Defense University [NDU], March 2009).

# CHAPTER 1. R&D IN DIFFERENT ENVIRONMENTS

This chapter compares and contrasts the R&D process in different environments—commercial R&D, government R&D, academic research, and research in free-standing research institutes.

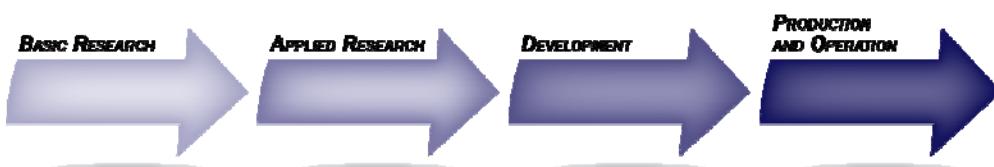
Science is the process of gaining understanding of the natural world. It produces theories and laws that describe the behavior of the various aspects that make up our world and our universe. Scientific research is an organized method of learning about this behavior. A desire to push the frontiers of knowledge motivates much of scientific research. This research is often termed curiosity-driven research or a search for understanding.

Engineering is the application of scientific knowledge to solve real-world problems and to design and implement creative new concepts for manmade systems. Engineering research seeks to develop new or improved design and fabrication techniques. Engineering science is a term used in some universities to describe fundamental research into the behavior of real manmade systems. Some fields of engineering research have moved, over time, from engineering to science and vice versa; other fields have remained between science and engineering research. Examples of the latter fields include fluid dynamics and the non-linear behavior of structures in response to severe external stresses (earthquakes, high winds). Often, research in engineering uncovers gaps in scientific knowledge and thus stimulates new studies in the sciences.

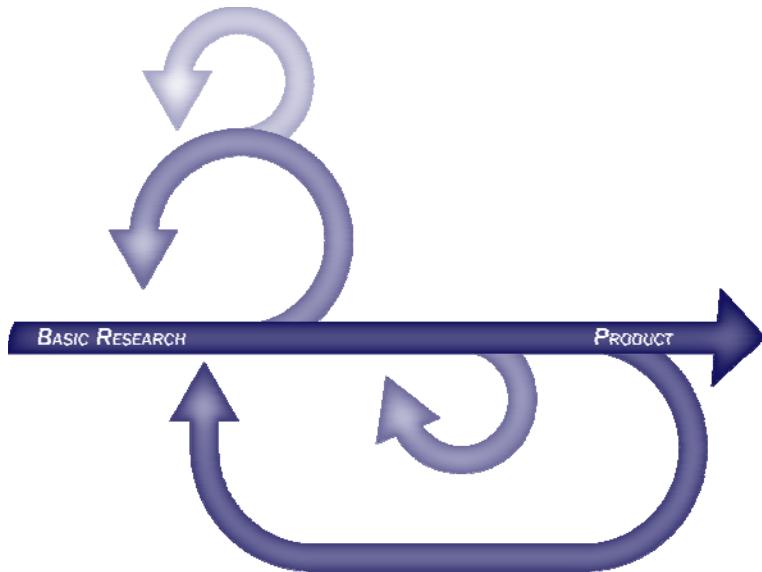
A new graduate considering a career in science and engineering probably has little idea that there are different kinds of laboratory research. I didn't. The graduate will discover that both science and engineering include basic and applied research. There are laboratory opportunities in product development for new products or for improvements to existing products. Scientists and engineers are involved in research on manufacturing processes. As product research matures, the work shifts to advanced development—the creation of early prototypes—followed by efforts to move the concepts into manufacturing and technical development of the market.

After World War II, the relationships among these different kinds of R&D were debated, especially regarding how to move from military R&D to broader topics in civilian science and engineering. Early rationalizations came to be known as the linear model. In the linear model, as shown in Figure 1, basic research begets applied research begets development begets production and operations.

The linear model is a simplification; sometimes the cart comes before the horse. Occasionally, basic research is performed after the applications have been developed, as happened, for example, in thermodynamics and the steam engine. The steam engine was developed about a century before the science of thermodynamics rationalized the behavior of the engine. Metallurgy and ceramics were practiced millennia before we understood phase diagrams or the effects of microstructure on material properties.



**Figure 1. Simple Linear Model of the R&D Process**



**Figure 2. Linear Timeline With Recursive Loops That Return to Earlier Phases of Research to Address Various Problems<sup>2</sup>**

Two-dimensional models are useful. The two-by-two diagram developed by D.E. Stokes is a popular model that deals with the difference between basic and applied research.<sup>3</sup>

The vertical axis determines the extent to which scientific curiosity with no particular application in mind motivates the technical work. The horizontal axis indicates the extent to which solving difficult practical problems drives the work. The plot is divided into two-by-two boxes, but it could also have been drawn with the two axes as continua such that a particular project could be located anywhere on the graph. Stokes illustrated his idea by placing noted researchers in three of the boxes. Bohr's work on the structure of the atom was curiosity driven (pure basic research). Edison's work was said to be totally focused on the potential commercial uses of electricity (pure applied research). Pasteur's desire to treat diseases motivated him to perform fundamental or basic research studies (use-inspired basic research).

Much fundamental research today resembles Pasteur's—Stokes' main point.

Technical progress cannot be described in one dimension. In fact, serious knowledge gaps are often discovered during the applied research or advanced development stages. These gaps can only be filled by returning to portions of the basic research stage to better understand the phenomena involved.

In very fast-moving disciplines, such as solid state physics and electronics, basic and applied research must sometimes occur simultaneously—often in the same research group. The model would then show recursive loops that may go all the way from problems arising in manufacturing processes back to basic research.

		QUEST FOR FUNDAMENTAL UNDERSTANDING	
		Yes	No
No	Yes	Pure basic research (Bohr)	Use-inspired basic research (Pasteur)
	No		Pure applied research (Edison)

**CONSIDERATIONS OF USE**

**Figure 3. Stokes' Two-Dimensional Model of Research Showing Differences in Motivation**

<sup>2</sup> John W. Lyons, *Two Traditions ... Whose Time Has Passed*, The Carolyn and Edward Wenk, Jr. Lecture in Technology and Public Policy, Johns Hopkins University, April 24, 1998.

<sup>3</sup> D.E. Stokes, *Pasteur's Quadrant—Basic Science and Technology*, Brookings Institution Press, 1997.

## **Basic vs. Applied?**

*In practice, use of the terms “basic research” and “applied research” is often not very meaningful. As noted in Figure 3, motivation is often the defining factor. How is one to classify a particular project? Is it up to the individual investigator—how he or she views it—or is it up to the institution that sponsors the work (e.g., the Congress or the Pentagon)? I once heard the Chair of the National Science Board argue that the distinction is unhelpful. I agree.*

*In some Federal agencies, no official distinction between basic and applied research exists in program planning or budgeting. For example, when I was Director of the National Institute of Standards and Technology (NIST), research was research. Each year when the National Science Foundation (NSF) queried NIST as to how much of its work was basic research, we lacked an indicator for that metric in our management system. Instead, we asked senior managers for an estimate, which we would then submit to NSF.*

*In the Army, where basic research is called 6.1 in the budget and applied research is called 6.2, I spent time in fruitless discussion over whether a new proposal was one or the other. The Pentagon’s definition of basic research holds that basic research is work that is not motivated by solving any particular problem. This definition is manifestly silly. I would wager that almost no one in the Army laboratories or the Army Research Office mounts a new program that has no utility for the Army in mind. Even in the case of quantum computing, we knew that success would support important military requirements, such as code breaking.*

*In my own work in the Army, I tried not to use the terms “basic” and “applied.” Rather, I found it more useful to describe much basic work as “long-term, fundamental” or “exploratory” research. These terms distinguished, in my mind, whether the work addressed pressing, very difficult problems requiring extensive and probably lengthy work or was aimed at more high-risk strategic objectives that would likely require pushing back scientific or engineering frontiers. I felt that exploratory research was a brief study of something new to see if we should consider a more serious effort. Typically, discretionary funds—rather than official programs—supported exploratory work. Long-term, fundamental work, on the other hand, was a serious, officially funded investigation of phenomena associated with a formal program. The purpose of long-term, fundamental work was to remove difficult, often longstanding problems in an area—problems that required application of the most up-to-date tools and concepts.*

*I am not alone in my struggles with these DOD categories and note a report from the National Research Council (NRC)<sup>4</sup> in which the committee remarked: “The committee decided that discussion of that issue [the difference between basic and applied research] is not productive, just as the distinction itself is not useful.”<sup>5</sup>*

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<sup>4</sup> Assessment of the Department of Defense Basic Research, Committee on DOD Basic Research, Division of Engineering and Physical Sciences, National Research Council (NRC), Washington, DC, 2005, p. 8.

<sup>5</sup> Ibid.

Coffey et al. recently discussed the evolution of technology with time.<sup>6</sup> The authors consider the development of radar by first looking back to the earliest scientific discoveries in theory and experiment and then moving forward in time to learn what ancillary developments had to occur before a radar system could be built. The story begins with James Clerk Maxwell's theoretical treatment of electricity and magnetism published in 1865. Maxwell combined the two into a theory of electromagnetic radiation.<sup>7</sup> Following this theory was Heinrich Hertz's demonstration in 1886 of radio waves and the fact that they can be reflected off objects. Before this information could be utilized in radar, power supplies, antennas, and similar tools were needed. It was only in the 1930s that all of these developments came together and a radar device could be demonstrated. It is possible to describe similar chains of linked advances in nearly all technical areas.

The radar example also illustrates convergence in S&T. Various pieces of the puzzle from different disciplines mature at different times, but they eventually converge to make something entirely new possible. A current case of convergence is that of telephony and computing, wherein smartphones contain computers, and computers are a key part of communications systems. I return to the idea of convergence later in this paper after Chapter 2 describes research laboratories, what they do, and what can make them great.

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<sup>6</sup> Timothy Coffey, Jill Dahlburg, and Eli Zimet, *The S&T Innovation Conundrum*, Defense & Technology Paper 17 (Washington, DC: CTNSP, NDU, August 2005).

<sup>7</sup> Of course, this was not really the beginning. The work of Benjamin Franklin in about 1750, Alessandro Volta in 1800, Andre-Marie Ampere in 1820, Hans Oersted in 1820, Michael Faraday in 1831, and so many others came before.

## CHAPTER 2. THE ROLES AND DESIRED CHARACTERISTICS OF RESEARCH LABORATORIES

As part of the 1991 cycle of military Base Realignment and Closure (BRAC) activities in DOD, the Congress directed that the Secretary of Defense appoint a Federal Commission (the “commission”) to review the plans of the three military services to restructure their laboratories.<sup>8</sup> Final BRAC decisions on relocating or closing laboratories were delayed pending the commission’s findings. The commission’s report<sup>9</sup> describes the DOD laboratories’ mission: “to provide the technical expertise to enable the Services to be smart buyers and users of new and improved weapons systems and support capabilities.”<sup>10</sup> The report lists a number of important functions, including the following:

- Acting as principal agents in maintaining the technology base
- Avoiding technological surprise
- Supporting the acquisition process
- Responding rapidly in times of urgent need or National crisis
- Supporting the user in applying emerging technology and introducing new systems.

A more recent report from the CTNSP elaborates the role of the Army laboratories<sup>11</sup> as follows:

- Performing in-house technical work—theory, modeling, experimentation
- Exploring new concepts and developing new knowledge
- Ferreting out, from external laboratories, new S&T of potential use to the Army
- Applying new knowledge to solve enduring Army problems
- Conducting developmental testing of new products or processes
- Conducting engineering research to aid in scale-up
- Facilitating transfer of technology to customers and users
- Providing technical advice to Army senior leadership, thereby enabling the Army to be a “smart buyer.”

And that report went on to affirm the commission’s list of attributes necessary for achieving high-quality, effective laboratories:

- Clear and substantive mission
- Critical mass of assigned work
- Highly competent and dedicated workforce
- Inspired, empowered, highly qualified leadership
- State-of-the-art facilities and equipment
- Effective two-way relationship with warfighters
- Strong foundation in basic research
- Management authority and flexibility

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<sup>8</sup> I was appointed from my position as Director of the National Institute of Standards and Technology (NIST) to serve on the Federal Commission.

<sup>9</sup> *Report to the Secretary of Defense*, Federal Advisory Commission on Consolidation and Conversion of Defense Research and Development Laboratories, Office of the Secretary, DOD, Washington, DC, 1991.

<sup>10</sup> Ibid.

<sup>11</sup> John W. Lyons, Joseph N. Mait, and Dennis R. Schmidt, *Strengthening the Army R&D Program*, Defense & Technology Paper 12 (Washington, DC: CTNSP, NDU, March 2005).

- Strong linkage to universities, industry, and other government laboratories.

These roles and attributes are broadly applicable to most if not all research laboratories, not just DOD laboratories. However, not all of the attributes will be found in all laboratories. For example, basic research is not always a component of smaller laboratories. In recent years, some companies—and indeed entire industries—have relied on universities for most of the basic research work of interest to the companies. Companies often sponsor such work. The following are some distinguishing characteristics of laboratories working in different parts of society—industry, government, universities, and independent research institutes.

**Industrial laboratories** operate research programs depending on the emphasis of the company and its customers. This work includes looking for new ways to increase the company's business and decrease costs. Customers' needs create a "demand pull" on the laboratories. These needs may be for improved existing products or for new products (product research). Sometimes customers simply want a lower price, thereby increasing the laboratories' focus on cost reduction in manufacturing processes (process research). Often the company is helping customers apply its products or developing new uses for its products (applications research).

### ***Chemical Applications in the Field***

*My first task at the Monsanto Research Laboratory was to screen the company's products for use in treating sub-base soils under highways to overcome the tendency of clay soils to lose bearing strength when wet. After training at the then-U.S. Bureau of Public Roads in Washington, DC, the test work began. Fortunately, one of the company's products showed promise in laboratory exposure tests; two state roads laboratories were kind enough to run laboratory and field tests. Ultimately, we installed two test strips in roads in Missouri and Georgia. We built our own rig for handling and applying the chemical and went out with the road crew to oversee the application; we ran soil tests as the work proceeded. (At one point on a country road in central Missouri, a local farmer appeared carrying a shotgun. He told us not to worry—that one of his large hogs was roaming loose. The shotgun was loaded with rock salt, which the farmer used to encourage the hog to go back to the farm. The hog obliged.)*



**Figure 4. The Author Helping Build a Test Road in Central Missouri Using His Technical Findings From the Lab**

For those companies that allow their laboratories to conduct some basic research, newly emerging technologies can open new opportunities for R&D. Alternatively, a company may buy its way into new areas and expect its laboratories to develop scientific and engineering support for the new area. The company makes these decisions as part of its strategic planning.

Some companies limit their overall missions very specifically; others are open to moving into new areas. For the latter, the laboratories have latitude to investigate many new or emerging technologies. Examples certainly include the former Bell Laboratories, the IBM research laboratories, the 3M research programs, and the work of the Xerox Corporation, especially at its Palo Alto Research Center.

The authorizing legislation of **government laboratories** specifies these laboratories' mission areas—sometimes very specifically, sometimes loosely. The work actually performed depends on the appropriations process; without funds, the authority is of little value. The National Institutes of Health (NIH) laboratories are divided into 27 institutes and centers, each of which the Congress has authorized. Each has a mission to address a specified area of medical research. The Department of Energy (DOE) operates a set of "National Laboratories" that the Government owns but that operate under contract to the private sector. They each originally had a very specific mission related to nuclear weapons and energy problems. Since the end of the Cold War, these laboratories have sought additional mission areas and have broadened their scope based on their general competences in science and engineering. Compared to these laboratories, the DOD laboratories have a very focused role: DOD concentrates on research in support of the warfighter.

Some congressionally specified missions are nonetheless very flexible. For example, as one of its missions, NIST must develop the measurement methods and standard reference information needed by U.S. industry, academia, and government. As a result, when industrial emphasis shifts, NIST follows (or, one hopes, anticipates) the new needs and shifts its programs accordingly. This shift in focus is likely true of other agency laboratories, such as those in the Department of Agriculture and Food and Drug Administration.

In **university laboratories**, the focus is pretty much on the individual investigator's interests, provided funding is available. University research can be divided into two categories: (1) the work of professors and their students supported in part by grants and contracts and (2) the work of large university centers that are almost always dependent in whole or in part on sponsors from government or industry. In the first category, the professors may be funded by the university, but the students are funded by money from grants or contracts to the professors or by awards directly to individual students from government. The professor may propose a new area of work to sponsors such as NSF, DOE's Basic Energy Science Office, or NIH; if the professor wins a grant or contract, he or she is able to start on a new area. That mission area is whatever the professor wishes, depending on securing support.

**Independent research institutes** are not affiliated with any of the above categories; rather, they are set up as free-standing entities. They may be supported by very large bequests, such as the Howard Hughes Medical Institute, which is funded from its endowment. Similarly, the Salk Institute was started by support from the March of Dimes but is now also supported by the NIH and other agencies. The Battelle Memorial Institute was formed from a bequest from the owner of a steel company and initially focused on metallurgy. It moved into many other areas and greatly expanded as a result of its sponsorship of what became the Xerox Corporation. Battelle developed a contract arm and became the operator of several government-owned laboratories

(Oak Ridge, Pacific Northwest, and Brookhaven).<sup>12</sup> Battelle is an excellent example of the advantages of being free from a restrictive mission statement.

**Comments.** The foregoing discussion of the various kinds of research entities in the United States likely applies to most advanced countries around the world. Most of these countries have government laboratories for functions such as defense, standards, health, and energy. The laboratories may have different names. In China and Russia, many leading laboratories come under their academies of science. In Japan and Europe, first-rate government, university, and industrial laboratories exist much as in the United States.

The United States has bilateral and multilateral cooperative agreements in S&T with many foreign countries. The DOD has both types of agreements. The most productive of these agreements facilitate exchange of information, exchange of scientific staff, and occasional joint collaborations. A recent example of research collaboration is the International Technology Alliance between the United States and the United Kingdom (UK) in network and information science. This alliance comprises two linked consortia managed by IBM—one in the UK and one in the United States—with members drawn from industry and academia. The agreement ties these consortia very closely to the U.S. Army Research Laboratory (ARL) and the UK Ministry of Defence, which are the two sponsors of the effort.<sup>13</sup>

This chapter has considered the kinds of scientific research and the institutions that conduct or sponsor it. There are many different opportunities for technically trained people to pursue their careers. I have listed some of the factors one should consider when choosing a position in a research laboratory.

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<sup>12</sup> See <<http://www.battelle.org/ASSETS/36DC84C50C0049778FAE3A68E7FD1F02/75.pdf>>

<sup>13</sup> John W. Lyons, *Army R&D Collaboration and the Role of Globalization in Research*, Defense &Technology Paper 51 (Washington, DC: CTNSP, NDU, July 2008).

## CHAPTER 3. IN-HOUSE VS. EXTRAMURAL RESEARCH; COLLABORATION

The work of a laboratory may be done entirely in house, or it may be contracted. If some of the work is contracted, it may stand alone (separate from in-house work) or be tightly connected to an in-house effort (a formal collaboration). Both approaches are used. This chapter discusses some examples and argues for doing more collaborative research under certain conditions.

In my experience in industry, the laboratory did not sponsor much external work. Senior company management usually handled any external work, which involved funding universities for work not closely related to the in-house effort and intended to diversify the company. In recent years, the chemical industry has reduced or eliminated its in-house basic research and has turned to academe to perform such work.

The Government's funding of extramural research began in earnest in World War II for military purposes. After the war, the question was how to sustain the very considerable private sector capabilities created by wartime government funding. The first effort was the creation of the Office of Naval Research (ONR) established by the Congress in 1946. ONR is a funding agency and does not have a laboratory. However, in addition to its extramural funding, it is the principal source of funds for basic and applied research at the Naval Research Laboratory. (Today, each of the military services operates a research office for extramural work. The other two are the Army Research Office and the Air Force Office of Scientific Research.) The purpose of creating ONR was to continue the programs started during the war and to discover new technologies for naval warfare.

In 1945, Vannevar Bush prepared the report *Science, The Endless Frontier*.<sup>14</sup> This report recommended, based on the success of the military research done during World War II, that the Government should remain engaged in sponsoring research in S&T. The report recommended what became NSF in 1950. NSF administers a broad program of grants to universities to promote the discovery of new knowledge and to help in the training of new investigators. NSF does not have a matching in-house research laboratory. Two other major grant-making agencies are DOE's Office of Science and NIH. DOE's Office of Science not only makes grants but also manages 10 of DOE's laboratories. NIH manages its grants separately from its in-house laboratories, but its laboratory staff participates in reviewing proposals.

NIST has both laboratories and extramural programs, but this has not always been the case. The laboratory was previously strictly in house, and staff did not have oversee external work. In the 1970s, the Congress transferred a group of university grants on fire science and engineering from NSF to NIST (which was then the National Bureau of Standards [NBS]) Center for Fire Research (CFR). This was not a popular move in the eyes of many NBS senior managers, who felt that managing a portfolio of extramural programs would distract the in-house staff from their bench research. However, the transferred programs became an integral part of the in-house research; the group leaders at CFR were made responsible for overseeing the grantees' work, and

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<sup>14</sup> Vannevar Bush, *Science, The Endless Frontier*, A Report to the President by Vannevar Bush, Director of the Office of Scientific Research and Development, U.S. Government Printing Office, Washington, DC, 1945. Available at <<http://www.nsf.gov/od/lpa/nsf50/vbush1945.htm>>.

the work was planned so as to play an important role in CFR's internal efforts. This approach created an integrated NBS-private sector center of excellence in fire research that many soon considered the best in the world. Thus, CFR demonstrated that research could be managed all of a piece with part in house and part external. This lesson has been used as a basis for subsequent initiatives at NIST and ARL.

In 1988, the Congress, in its reauthorization of NBS, changed NBS' name to NIST and added new extramural functions. One was the Advanced Technology Program (ATP), which consisted of contracts awarded to individual companies or consortia of companies large and small with or without university partners or other government laboratories. The purpose of ATP was to foster innovation by bridging the innovation gap—sometimes called the “Valley of Death”—between early laboratory findings and the more expensive advanced development necessary before going to the marketplace. A generally accepted belief was that industry and venture capital firms were not pursuing basic research results because the risks were too high. The goal of ATP was to help bear the financial burden in areas with market potential. The program was loosely patterned after the Japan Key Technology Center program created in 1985 for the same reasons.

In 1991, NIST created a new office to manage ATP. NIST laboratories did not formally collaborate with the ATP awardees but were involved in both reviewing proposals and accepting temporary assignments in the ATP office. A succession of external reviews<sup>15</sup> judged the program as very successful, but it became a political liability. Some in Congress believed ATP, in picking likely commercial winners, was crossing a line into the business of the private sector. Efforts were made first to restrict the program's growth and later to eliminate it. These efforts finally succeeded. In ATP's place, the Congress created a successor program called the Technology Innovation Program.<sup>16</sup> It is too soon to know how this program will fare.

The overall point of this discussion is that NIST has successfully managed a large extramural program while maintaining a very high-quality internal laboratory. (Three NIST staffers have won Nobel Prizes in recent years; the work of two others was prominently discussed in Nobel citations.)

ARL has found it useful to create external consortia in critical areas to fill gaps in its internal competencies. In the early 1990s, the Army decided to digitize the battlefield. ARL's challenge was to help develop and adapt the technology needed for digital communications and command and control of the battlefield. This technology needed to comprise a computerized fighting platform system of systems. ARL had not previously focused on this kind of work, but simply contracting out the necessary research would not have increased ARL's internal expertise in the long term.

In response, ARL utilized a new kind of contract called a “cooperative agreement” (not to be confused with the Cooperative Research and Development Agreements that had become popular at that time). In this approach, a consortium—led by a company with experience in building and fielding such systems—was to perform the external research. The consortium had to have at least one major research university and one historically black college or university; it could have other

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<sup>15</sup> *The Advanced Technology Program: Assessing Outcomes*, Board on Science, Technology, and Economic Policy, NRC, National Academies, Washington, DC, 2001.

<sup>16</sup> The Technology Innovation Program at NIST was created in 2007 by the Congress in the America Competes Act.

members as well. The consortium was to be closely connected to ARL laboratories through joint program planning, and a committee chaired by a senior ARL manager was to perform overall management.

The initial funding was for three such consortia for a period of 5 years at \$5 million per year per consortium.<sup>17</sup> To improve communication between ARL and the consortia and to speed the transfer of new findings to ARL (and to relay new Army needs to the consortia), a provision required long-term rotations of staff members to and from the consortia. The experiment began in 1995, was judged by the Army and the Congress as successful, and has been expanded over the years. The program is the Collaborative Technology Alliances (CTA). In 2001, there were five CTAs, each funded for 5 years at \$7 million per year with an optional 3 years at about \$3 million per year. An additional CTA was established in 2008 at \$38 million for 5 years and an option of \$51 million over the following 5 years. More recently, a CTA was established in network science and another in cognition and neuroergonomics. This new model for collaboration between ARL and the private sector is progressing well.

In 2006, ARL and the UK Ministry of Defence established an International Technology Alliance in network and information sciences. There are two parallel consortia—one in the UK and one in the United States. The project is funded at about \$135 million for a period of up to 10 years. This project links consortia in two countries across the Atlantic Ocean. It has been called a breakthrough in international research. Whether or not such consortia will be established in other international areas is unclear.<sup>18</sup>

The focus in the next chapter is on the interactions among research personnel without necessarily having formal contractual arrangements. We will see that collaboration is a common characteristic of research at the level of the individual at the bench.

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<sup>17</sup> E.A. Brown, *Reinventing Government Research and Development: A Status Report on Management Initiatives and Reinvention Efforts at the Army Research Laboratory*, ARL-SR-57, Army Research Laboratory, 2800 Powder Mill Road, Adelphi, MD, 20783-1197.

<sup>18</sup> John W. Lyons, *Army R&D Collaboration and the Role of Globalization in Research*, Defense & Technology Paper 51 (Washington, DC: CTNSP, NDU, July 2008).

## CHAPTER 4. THE INTERACTIVE ENVIRONMENT FOR THE INDIVIDUAL RESEARCHER

*“No man is an island, entire of itself...” John Donne, Meditation XVII*

A statement similar to Donne’s can be made about researchers and research laboratories: No single researcher or laboratory can operate in isolation from its peers, nor could it if it wanted to. There is simply too much knowledge in the world today for any one laboratory to have command of it all, even in its own area of specialization. When considering the role and effectiveness of a research laboratory, one needs to understand a laboratory’s place in the broad landscape of research institutions worldwide. Except for highly classified work, research laboratories are connected to other laboratories by a variety of links. Information flies relatively freely back and forth, thereby making possible the early sharing of results and enabling many types of collaboration. These considerations suggest that practitioners in the 21st century will base their research on a more complete understanding of the “state-of-the-art” and will benefit from the assistance of many colleagues around the world.

The scientist or engineer working in a research laboratory receives information continuously from a wide variety of sources. By participating in this information flow, the individual becomes a contributing member of the international technical community. To be effective and to avoid technical surprise, the individual must maintain external contacts, keep up with technical literature, attend meetings, and visit other laboratories. A way to think about this is to consider the individual researcher positioned in the center of a circle of communication links (see Figure 5) that may also be the basis of close working partnerships.

Figure 5 shows four categories of contacts or activities: one-on-one personal interactions, participation in formal programs with other laboratories, technical literature review and creation, and professional activities.

Direct personal contacts include daily discussions with colleagues in one’s own laboratory. Sometimes discussions at the lunch table lead to important new approaches. Sometimes whiteboards are installed in laboratory corridors to facilitate informal communication among staff from different lab modules. Discussions with collaborating personnel in client laboratories are a routine part of any research program and are necessary to help shape the next steps of a program. When a formal collaboration with other laboratories occurs, continual interactions among the personnel are essential to broaden understanding and to avoid unnecessary duplication of effort. Personnel can enhance this interaction by traveling to the partner’s laboratory or even serving a term as a visiting scientist or engineer there. On occasion, a scientist or engineer is assigned to oversee or maintain cognizance of work being done under contracts or grants. This assignment is an opportunity for the individual to broaden his or her horizons while advancing the program.



**Figure 5. Information Flows to and from an Individual Researcher**

A key part of any serious researcher's responsibility is to maintain awareness of, and contribute to, progress in his or her professional field. To do so, the researcher must first keep up with the technical literature in his or her areas of interest by scanning journals and studying selected publications. Services that provide abstracts of publications and, in particular, online communications help this effort considerably. One can connect online to the local technical library, read the tables of contents of the journals, and select certain journals for detailed study. The actual papers may be available on line, or the journals may be in the library and available for either library study or copying. For learning about specific topics, various on line search engines are invaluable. Researchers have little excuse for not knowing what is going on in the rest of the technical world.

By the same token, the individual researcher should share his or her knowledge and help others improve their understanding by contributing his or her findings to the literature—subject to proprietary or security restrictions. Researchers can contribute papers, write monographs summarizing progress in a field, give talks at technical meetings, and actively participate in seminars.

Many forms of professional activities contribute to information sharing. Membership in professional societies brings with it subscriptions to journals, attendance at society meetings, and regular meetings of local sections of National societies. These activities present additional chances to listen to guest speakers and share experiences with fellow members. Another way to gain new information is to agree to serve on special committees or commissions, which are often National or international in scope. The NRC of the National Academies conducts all kinds of scientific and technological investigations and related policy studies for the U.S. Government. Members of study panels are drawn from a variety of sources, and interactions among committee members and government sponsors are often as valuable as the results of the study. The same is true for service on National studies commissioned by the U.S. Congress.

Another form of professional activity is developing close ties between local universities and the in-house research staff.. These relationships can include giving talks to students, serving as adjunct professors, accepting membership on visiting boards, and enrolling in continuing education courses.

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Now, consider a group of such researchers each surrounded by all of these information channels, and then imagine connecting all of the researchers in the world by fiber optics and the Internet, and you get some idea of the social and technical networking that occurs continuously.<sup>19</sup> This same network makes possible collaborative research at home and across the oceans. The Internet enables almost continual exchanges during the progress of experimental work. Collaborators can conduct theoretical studies anywhere an Internet connection exists. A team of collaborators can work on a single shared software package to perform engineering design.

There are two barriers to taking advantage of these opportunities. One is industry reluctance to share technical information with potential competitors; the other is the need to protect classified

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<sup>19</sup> Thomas L. Friedman, *The World is Flat*, Farrar, Strauss, and Giroux, New York, 2006; John W. Lyons, *Army R&D Collaboration and the Role of Globalization in Research*, Defense & Technology Paper 51, (Washington, DC: CTNSP, July 2008)

information in some DOD and National security-related work. The proprietary concern is one of protecting trade secrets and intellectual property. In the case of the consortia established by ARL in the private sector, each consortium is required to establish its own rules for handling intellectual property among members before bidding for work. The National security issue has proved harder to deal with, especially since the terrorist attacks of September 11, 2001. Recent CTNSP publications discuss this issue.<sup>20</sup> The concern is not with how to protect classified information—we know how to do this. The issues are in an intermediate area of unclassified but sensitive information—a gray area often labeled by the DOD as For Official Use Only (FOUO). FOUO means the results cannot be published in open literature. There are costs to this control of sensitive but unclassified work. There are the actual costs of fighting through the bureaucracy to obtain approvals, but perhaps more important is the cost of lost opportunities. National Security Decision Directive 189, issued by President Reagan, declares that basic and applied research results should not be classified except under specified conditions and that results should be openly shared in the literature. However, agencies have been reluctant to comply with this directive.

I have discussed how laboratories can collaborate formally and, in this chapter, how individuals work together not only in their work assignments but also in their professional lives. In the next chapter, I present views on how to manage a laboratory or, indeed, a group of laboratories.

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<sup>20</sup> John W. Lyons, *Army R&D Collaboration and the Role of Globalization in Research*, Defense & Technology Paper 51 (Washington, DC: CTNSP, NDU, July 2008); William Berry and Cheryl Loeb, *China's S&T Emergence: A Proposal for U.S. DOD-China Collaboration in Fundamental Research*, Defense & Technology Paper 47 (Washington, DC: CTNSP, NDU, March 2008). Also see *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*, Committee on Science and Public Policy, National Academies, National Academies Press, Washington, DC, 2007, p. 105.

## CHAPTER 5. MANAGING LABORATORY RESEARCH

Chapter 5 covers lessons I have learned from managing R&D in industry and two government laboratories. The role of the research manager can be thought of in terms of five different activities: planning, organizing, staffing, directing, and external relations.<sup>21</sup> These activities also contain additional subcategories. A summary of my experiences of these roles follows.

**Planning** begins with an agreement as to the laboratory's functions and mission. The laboratory director reviews requests and proposals for continuing, expanding, or shrinking existing programs and for starting new work. These proposals come from the laboratory middle managers and technical staff, as well as suggestions from external parties. (Sometimes congressional earmarks mandate work on specific topics.) The director compares the requests with the mission and with the laboratory's capabilities and then makes a set of decisions. The decisions may be entirely internal, as with refocusing existing programs, or may be external, as with presenting budget proposals for new initiatives. Over time, these decisions shape the program and develop the character of the laboratory, its effectiveness, and its reputation.

In the Government, the most rigorous planning for S&T programs occurs during the formulation of the Federal budget. Senior managers spend large amounts of time preparing the budget, defending it before the several layers of bureaucracy that must approve it, and then helping defend the budget before four congressional committees (two authorizing committees and two appropriations committees). Typically, laboratory management works on three separate budget years at once—formulating the next budget, defending the current budget before the Office of Management and Budget (OMB) and the Congress, and executing the previously approved budget. My experience as the Director of NIST was to handle the budget presentations to the Congress, sometimes accompanied by the next level down of NIST management. In contrast, in the DOD, my interaction with top DOD budget staff and with congressional committees was limited.

An important part of planning is determining the balance between short-term work and longer term, fundamental research. A part of this determination is deciding how much of the long-term research should go beyond the accepted mission of the laboratory or the parent organization. This research can be the basis for expanding or, indeed, changing the nature of the parent enterprise.<sup>22</sup>

*An example of considering the limits of the laboratory mission at ARL was deciding whether to fund work on quantum computing. Back in the late 1990s, this subject was at a very early stage—mostly in development of theory. One of the ARL staffers became interested in it and developed relationships with some external collaborators. He asked me for some of my reserve funds to continue his work. The topic was clearly outside the laboratory's current portfolio, but it represented a possible major advance in computer technology that would, perhaps someday, be very important to the Army. I felt we*

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<sup>21</sup> A useful general reference for this subject is Hans Mark and Arnold Levine, *The Management of Research Institutions*, NASA SP-481, NASA Scientific and Technical Information Branch, National Aeronautics and Space Administration, Washington, DC, 1984.

<sup>22</sup> John W. Lyons, Joseph N. Mait, and Dennis R. Schmidt, *Strengthening the Army R&D Program*, Defense & Technology Paper 12 (Washington, DC: CTNSP, NDU, March 2005).

*needed to keep a window open in this area even though we would not request budgeted funds to establish a formal program. So, I allocated some of my reserve funds, and the individual continued his work and maintained cognizance of new developments for ARL. Given the advances that have been made in this field, I think the decision to fund the work was the right one.*

Forecasting long-term developments in S&T has not been a regular activity in the Army. The last time this was done was in 1992.<sup>23</sup> Recently, a more advanced technique has been introduced called convergence forecasting. In this approach, clusters of somewhat related sciences or technologies are forecast for, say, 25 years ahead, and then the potential is projected for two or more disciplines coming together (converging) to enable new capabilities.<sup>24</sup> The manager or director of research certainly makes use of some form of forecasting when making decisions on the mix of programs he or she will support. For me, this was an informal and sometimes subconscious thought process resting on a continuous stream of technical information gleaned from staff, from my reading, from sitting in on meetings, and so on—activities that formed my basis for assessing new proposals. Some managers rely on quantitative assessments based on scoring a number of attributes. Some more formal technique of assessing opportunities in the future should be helpful as the pace of technological developments accelerates.

**Organizing** the laboratory to address its critical functions is another responsibility of the director. Some say the shape of the organization should reflect the management style of the director; others say the organization must be structured to encourage free information exchange among the staff and collaboration on project work. Both ideas are correct. My experience is that the major organizational units within the laboratory need to be big enough to stand on their own feet (i.e., have enough resources so that they can set aside reserve funds for new ideas and for survival of the occasional budget shortfall). Flat organizational structures are more effective in promoting internal communications and cooperation within the laboratory than are older hierarchical structures. The latter can create “stovepipes” or vertical paths of responsibility and often separate functions that would be more effective together. For example, product research is often separate from process research in industry.

A new, high-priority demand for research that the laboratory has not been organized to address may require the creation of new divisions or directorates. In industry, this occurred fairly often as the customer base shifted its interests. At NIST, major new research initiatives sometimes resulted in the formation of new laboratory units. Examples are fiber optics, biotechnology, computer security, and factory automation. The Army’s decision to digitize the battlefield led to a new directorate within ARL, as well as the creation of a new kind of external collaboration—the CTAs.<sup>25</sup> The Internet has enabled such new tools as the Defense Research and Engineering Network (DREN), which was designed originally to provide high-speed connections among the

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<sup>23</sup> STAR 21—*Strategic Technologies for the Army of the Twenty-First Century*, Board on Army Science and Technology, Commission on Engineering and Technical Systems, NRC, National Academy Press, Washington, DC, 1992; John Lyons, Richard Chait, and Jordan Willcox, *An Assessment of the Science and Technology Predictions in the Army’s STAR 21 Report*, Defense & Technology Paper 50 (Washington, DC: CTNSP, NDU, July 2008).

<sup>24</sup> John W. Lyons, Richard Chait, and James J. Valdes, *Forecasting Science and Technology for the Department of Defense*, Defense & Technology Paper 71 (Washington, DC: CTNSP, NDU, December 2009).

<sup>25</sup> See the discussion in Chapter 3, page 12.

six DOD Supercomputing Resource Centers, also called Major Shared Resource Centers. Today, new groups are also emerging to deal with cybersecurity.

**Staffing.** The capabilities of the technical staff represent the single most important asset and factor in laboratory success. Ensuring a top-quality staff requires an aggressive, well-organized recruiting program with the ability to react quickly to hiring opportunities. A number of factors motivate those who enter the R&D profession—the most important of which is usually *not* salary. Researchers do not sign on for a high salary but for the career opportunities. They want a reasonable salary and to be treated fairly in pay administration. Strong motivators include the nature of the mission and the work, stimulating colleagues, up-to-date facilities and equipment, supportive management, opportunities to collaborate with experts internal or external to the laboratory, approval to attend technical meetings, visits with other laboratories, and the freedom to publish or patent results.

In industry, recruiting for research talent is a formal activity performed collaboratively among the human resources staff and the research managers. Laboratories establish close working relationships with university placement offices and with National professional groups. Certain recruiters are authorized to make employment offers on the spot. In the Federal Government, recruiting is much more of a challenge. In theory, positions are filled by publishing notices of vacancies at the Office of Personnel Management. In practice, many high-level technical positions are filled through an informal process involving personal contacts maintained by research staff. (Some laboratories in the Army have recently acquired direct hire authority.)

When a particularly promising individual is located, there are some other options beyond simply posting a position opening or attempting a direct hire. For a candidate just completing a doctorate, one option is that the candidate apply to the NRC's Research Associate Program; these are usually termed “post-doc” positions. The short-term nature of such an appointment—usually 2 years—gives the post-doc a chance to size up the laboratory and decide whether or not to seek to stay on as a permanent employee. Similarly, it gives the laboratory the opportunity to decide whether the post-doc is a good fit with the organization. NRC only makes post-doctoral appointments for laboratories with qualified mentors on staff. Success as a post-doc can lead to conversion to a regular full-time, permanent position. (NRC's publication of opportunities and subsequent screening of applicants meets the Federal requirement for competition.) My experience has been that up to about one-half of post-docs ultimately convert to permanent positions. These people have been among the very best new hires.

Sometimes one can use regular competition for senior positions requiring special expertise. The requirements are specific enough that only a few individuals can qualify. The Government has authority, in special cases, to recruit very senior individuals with special qualifications non-competitively. However, this occurs only rarely. To stimulate recruiting efforts, the research director may establish performance metrics for managers to establish success rates in recruiting for post-docs or for regular appointments. I used metrics in this way at ARL.

Once onboard, the new employee should have a member of the senior staff as a mentor, as well as a recently hired employee to help negotiate local administrative procedures. Retention bonuses are a way to overcome tempting offers from outside. Laboratories should have a performance metric to evaluate managers' ability to retain the best performers.

**Managing Senior Professionals.** Any laboratory must have a few true stars who are key to moving the work ahead and developing new areas. Some of these may be prima donnas and may require careful managing.<sup>26</sup> Some stars will deserve special resources and laboratory space; some should be allowed to have a staff of at least a few permanent employees, post-doctoral fellows, and guest workers. When I was at Monsanto Company, a special class of “stars” was singled out by management. Most had non-administrative positions. They were designated “Monsanto Scientist” and “Monsanto Senior Scientist” and worked independently. At NIST, we studied the IBM Fellows program. At the time, IBM Fellows were set up with 5-year funding and allowed to work on whatever interested them; a review after 5 years was required to provide the basis for continuing funding. NIST established NIST Fellows and Senior NIST Fellows. These Fellows are allotted special funding and work mostly independently. The appointments are permanent; some Fellows, on retirement, have been designated Emeritus Fellows. At NIST in 1997, Senior Fellow William Phillips won the Nobel Prize in ultra-low-temperature physics. He had his own group of associates, ample funding, and excellent equipment. He had the enthusiastic support of his management. When asked why he stayed at NIST and resisted various recruiters, he attributed it to the environment and to the research continuity he could achieve compared to other opportunities. (Two other NIST physicists subsequently won Nobel prizes—Eric Cornell in 2001 for the demonstration of Bose-Einstein condensates and John Hall in 2005 for laser-based precision spectroscopy.)

ARL has a category of ARL Fellows, some of whom are also Army STs. (ST positions are a category of senior non-administrative professionals with rank roughly equivalent to general officers.) I required that each ARL Fellow be funded entirely out of our appropriated base funds (“hard money”) and be provided, in addition to salary, additional funds for their use and under their control. I thought of the STs as rather like senior university professors, often with a group of graduate students or post-docs. I feel the STs should be granted considerable independence and opportunities to explore new areas. The Army only is authorized about 50 ST positions. There ought to be more.

Given that these appointments are based on many years of high-level performance, the incidence of poor performance has been, to my knowledge, nil.

**Directing** the laboratory means ensuring the people, equipment, facilities, and support services are in place. It means ensuring the work is in accord with research plans or that said plans are adjusted as research findings may justify. It means encouraging and motivating the staff. The director should be flexible in how he or she deals with personnel. Some personnel will need continual encouragement; others may only occasionally need to be energized. All require personal attention. Walking around the laboratory and hearing informally about new results is one of the great pleasures of serving as research director. I tried to set aside special times for these tours, pushing aside the distractions that are always present.

The research director is responsible for all aspects of the laboratory. The director must learn how to assimilate a great deal of information and distill it into manageable information packets that

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<sup>26</sup> An anecdote from baseball: When Joe McCarthy moved from manager of the Yankees to the Red Sox in the 1940s, he was asked how he would get along with Ted Williams. Ted had something of a reputation as being difficult, especially with the press and some fans. Joe’s reply was to the effect that if he couldn’t get along with Ted Williams, then he shouldn’t be a manager in major league baseball.

are useful as issues arise. This ability to absorb the essence of a presentation is particularly important when the subject is technical. Clearly, the director cannot know as much as the individual staff experts, but he or she must learn to grasp the core argument in just a few minutes. Occasionally the argument is unclear, and an additional briefing may be in order. If the subject is unclear, the fault may lie with the briefer. Some specialists are particularly gifted at compressing a complex subject into readily understood summaries; others are not. I had to negotiate around these characteristics and often had to study independently on my own time. Briefings are most productive when given in the laboratory modules where the work is being done.

The director should delegate authority and responsibility as much as possible. Support functions are critical to the success of the technical work; a very capable head of administration should be in charge. The director's staff handling budget preparation and monitoring program progress are important. Most of the director's immediate staff should have had prior experience in the laboratory to counter the common complaint that the staff around the director do not understand the challenges staff in the laboratories face.

The director should have a discretionary fund for supporting imaginative new ideas from the staff. This fund should be drawn from the base funding at levels from 2–3 percent up to 10 percent. A report of the White House Science Council's Federal Laboratory Review in 1983 suggests the latter figure.<sup>27</sup> (Known as the first Packard report, this report was the result of a series of visits by a panel appointed by the Council's chair to look into issues at the laboratories.) I created a director's fund, annually issued calls for proposals from the staff, reviewed the proposals with senior technical managers, and funded a few of the proposals for an initial exploratory phase—usually with enough money to support one professional and perhaps an assistant for 1–2 years. If the work demonstrated promise, I could then establish a new program and incorporate it into the budget. The results included extension of existing program scope and some entries into new areas.

Directing also includes overseeing management functions, including the fiscal side, to ensure compliance and solvency. Some would call this a separate function, or controlling. Theories of management sometimes separate the management functions from the leadership functions. I find that effective laboratory directors are both good leaders and good managers. The leadership function is more hands-on in terms of making technical decisions; the management function is more of overseeing how administrative staff handle day-to-day operations.

**Assessing Laboratory Quality—Peer Review.** To ensure high quality in a research laboratory, some form of independent, unbiased peer review is necessary. A recent report<sup>28</sup> discusses how such a review should be done. For timeliness and relevance, the user of the research results is best suited to evaluate the work—either the work solves the user's problems in a timely way or it does not. For technical quality, three somewhat different types of assessment are possible. External peers who are experts in their fields can evaluate scientific proposals. Grant-making entities, such as NSF, NIH, and the three DOD research offices, routinely perform external

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<sup>27</sup> Report of the White House Science Council Federal Laboratory Review Panel, Office of Science and Technology Policy, The White House, Washington, DC, May 1983.

<sup>28</sup> John W. Lyons and Richard Chait, *Strengthening Technical Peer Review at the Army S&T Laboratories*, Defense & Technology Paper 58 (Washington, DC: CTNSP, NDU, March 2009).

proposal review. Peer-reviewed journals can evaluate finished pieces of work and, in turn, submit the manuscripts to acknowledged experts.

To evaluate a laboratory's current work as a whole, it is necessary to assemble a panel(s) of experts from outside the laboratory. The panels visit the laboratory, listen to project presentations, tour the laboratory facilities, and sit down with management and research staff members. It is best, in the evaluation contract, to specify who will manage the review, how to address conflicts of interest, and the role of the laboratory managers. A body such as NRC has the advantage of being able to convene top experts and command respect for the credibility of the evaluation report. NRC insists on controlling the details and the conduct of the evaluation and has explicit rules for handling conflicts of interest.

By using external peer review, the laboratory not only obtains expert, critical assessments but also broadens its technical understanding through staff interactions with the panel members assembled by NRC or another contractor

### ***Peer Review of NIST and ARL***

*I first became involved with NBS when asked to serve on an ad hoc NRC panel to evaluate the Bureau's various programs in research on fire. NRC has operated peer assessments of the NBS/NIST laboratories for about 50 years. This panel on fire research made a series of recommendations that resulted in a substantial reorientation and consolidation of the work. The experience resulted in my leaving industry and taking a position to head up the NBS fire program. The NRC panel on fire research became a standing panel, meeting for assessments every year.*

*I established a similar set of NRC panels to assess the work of ARL under the NRC ARL Technical Assessment Board. This Board continues to conduct peer reviews of the ARL program. The reviews have been very helpful in pointing out potential areas of concern and generally strengthening the laboratory's work.<sup>29</sup>*

**Performing External Relations.** The head of the laboratory has many responsibilities: to the management chain above the lab, to the many clients and users of the laboratory's results, to the Congress, and to the general public. The director is, to a considerable extent, the external face of the laboratory.

As Director of NIST, I handled interactions with the Secretary of Commerce and the Commerce Undersecretary for Technology, with OMB, and with congressional committees. The congressional appearances dealt primarily with authorization and budget issues, but sometimes they were about specific investigations. For example, NIST had some responsibilities in building construction codes and building safety. Some of this involved investigating building collapses during construction and building failures during earthquakes. Notable testimonies were on the earthquakes in Mexico City in 1985 and San Francisco (Loma Prieta) in 1989. Another was a court-mandated study of a device reputed to produce more energy than was put in. (It didn't; see the sidebar below.) I testified on the performance of a copy protection scheme for digital tape recordings. (NBS questioned its reliability.) NBS management called these investigations "hot

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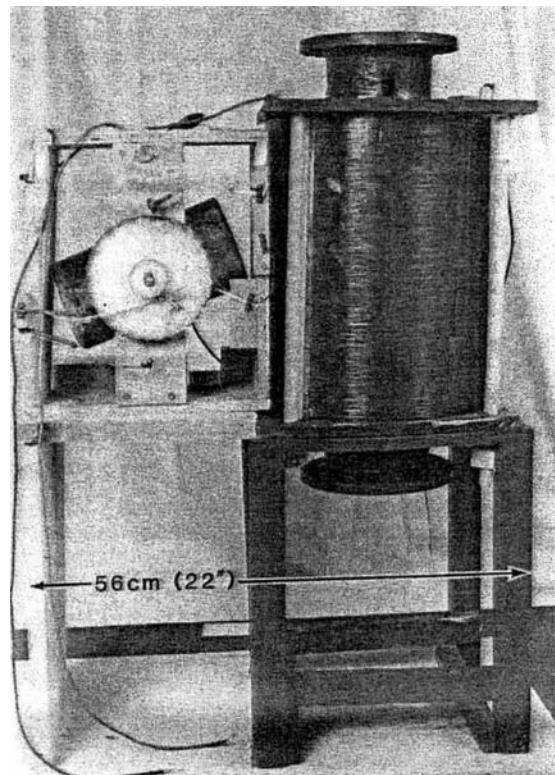
<sup>29</sup> NRC recently set up the Laboratory Assessment Board (LAB) and placed the NIST and ARL assessments under it. Additional laboratories have begun such assessments under LAB. The author is currently the chair of LAB.

potatoes” because of the great public interest and the liability issues often involved. NBS was very careful as to what could be concluded and how the findings were expressed. A recent NIST example is the major investigation of the September 11, 2001, collapses at the World Trade Center.<sup>30</sup>

### **Defending the Laws of Thermodynamics**

*NBS/NIST has long been used as a court of last resort in making difficult or controversial measurements. During my tenure, a number of very challenging assignments came to the laboratory, usually from the Department of Commerce, members of Congress, or other Federal agencies. On at least two occasions, the work was done to comply with proceedings in Federal court. One such example was the evaluation of an electrical device purported to produce more energy output than the energy input. The U.S. Patent Office had rejected an application for the device based on the laws of physics; namely, the law of conservation of energy and the second law of thermodynamics, which holds that perpetual motion devices are not possible. On appeal to Federal court, the Patent Office was directed to have NBS evaluate the claims of the inventor. NBS conducted, and reported in 1986, very careful measurements with special equipment not found in most laboratories. The laboratory in which the work was done was kept under lock and key, and the materials and equipment treated so as to maintain a clear trail of evidence. The upshot was that the device did not perform as claimed: “At all conditions tested, the input power exceeded the output power. That is, the device did not deliver more energy than it used.”<sup>32</sup>*

*NBS provided the results to the Patent Office and thence to the Federal court. I testified to a committee of the U.S. Senate. Nonetheless the inventor continued for many years to promote his device, without success.*



**Figure 6. Joseph Newman’s Energy Device. On the left is a rotating magnet; on the right, a very large copper coil. The setup connects to a large battery pack and a resistive load.<sup>31</sup>**

<sup>30</sup> For a lengthy series of references to NIST reports on the collapse of the World Trade Center on September 11, 2001, go to <<http://wtc.nist.gov/NCSTAR1>>.

<sup>31</sup> Ibid.

<sup>32</sup> Robert E. Hebner, Gerard N. Stenbakken, and David L. Hillhouse, *Report of Tests on Joseph Newman’s Device*, National Bureau of Standards Information Report 86-3405, National Bureau of Standards, Gaithersburg, MD, June 1986.

At ARL, relations with warfighter representatives were very important. ARL conducted visits and presentations at various sites of the Army Training and Doctrine Command to discuss soldiers' needs and recent research results. I reported to the four-star commanding general of the Army Materiel Command (AMC). In this role, I attended AMC command meetings at various AMC locations and participated in command group deliberations. I made presentations to many of AMC's suppliers as well. In budget and planning activities, I worked closely with the Deputy Assistant Secretary of the Army for Research and Technology and sometimes with his supervisor, the Assistant Secretary, who also was the Army Acquisition Executive. On occasion, I presented ARL work to the Director, Defense Research and Engineering

### ***In the Field With ARL***

*The work of researchers is usually fairly quiet and involves having a tolerance for long hours of careful and often repetitive experimentation, much of which fails for one reason or another and must be done over. The work of the research manager is equally fairly routine. However, on occasion something unusual occurs that leavens the day's work. Here is an example from my experiences as director of ARL.*

*My deputy director was a full colonel in the armor branch. He felt I couldn't be a proper manager of Army technology without intimate knowledge of Army combat platforms—especially the Abrams main battle tank. Aberdeen Proving Ground has extensive facilities for testing tanks, including test tracks for determining maneuverability and structural stability and also firing ranges for evaluating the tank's armaments. The colonel arranged for me to drive an Abrams on the track and fire the tank's main gun on the range. On the appointed day, I was dressed appropriately to drive the Abrams. The outfit included a helmet fitted with earphones. The driver's compartment is isolated from that of the tank commander, and communication between the two must be by radio. I observed this with some apprehension recalling that Michael Dukakis, candidate for president in 1988, was similarly photographed rising from the driver's seat of an Abrams with the helmet on. This picture somehow made Dukakis an object of derision by the Republican opposition. I cautioned the colonel and our entourage not to photograph me in a similar position. They did take such a picture and promptly published it in the ARL newspaper. I still have the framed photo as a treasured memento. Incidentally, the Abrams, with its 1,500 horsepower turbine engine, is smoother and easier to drive than most smaller vehicles.*

*The second part of this initiation was to go to a firing range at Aberdeen to fire the Abrams 120 mm main gun. This was the gun that dominated Desert Storm when supplied with the kinetic energy round known as the "silver bullet." So I climbed into the gunner's seat, was familiarized with the gun sight and trigger mechanism, and indicated I was ready. Through the sight, I focused on a target way down range, but I found that the target kept floating up out of view. I had to track it and guess when to fire. Needless to say, I didn't hit the target with any of several shots. I later learned that the gun's system for compensating for the effects of gravity was not turned on. I did gain a healthy respect for the gun in terms of noise and recoil. A considerable headache ensued.*



**Figure 7. The Author in the Driver's Compartment of an Abrams Main Battle Tank on the Test Track at Aberdeen Proving Ground**

All in all, the research director has many responsibilities outside the confines of the laboratory facility; the laboratory's staff help carry these responsibilities out.

## CHAPTER 6. RECOMMENDATIONS ON LABORATORY MANAGEMENT

Reflecting on my experiences at three different research institutions reveals a number of lessons widely applicable to any laboratory.

The laboratory at the chemical company was devoted to developing new products and new uses for existing products for a variety of industrial customers. Associated with this activity was process development for manufacturing new products and cost reduction of processes for existing products.

At NIST, the client base consists of scientists and engineers around the world who rely on standards for measurements, standard reference data, and standard reference materials. The entire technical community relies on NIST for these services. NIST is the Nation's court of last resort for physical and chemical measurements and, increasingly, for biological measurements. NIST's sister laboratories in other countries are not so much competitors but colleagues in obtaining and disseminating the best measurements.<sup>33</sup>

ARL is more like an industrial laboratory than a typical government laboratory; it is much more sharply focused. ARL is the central laboratory for Army materiel. Its responsibility is to conduct basic and applied research in support of the Army acquisition community's efforts. The work product of ARL is transferred to a set of engineering centers that carry out advanced development and then provide technical support to Army acquisition product managers. These product managers, in turn, complete the innovation cycle by converting prototype new products into fielded Army materiel.

Despite these differences, the lessons learned from managing these three laboratories are similar and applicable across the laboratories.

### ***1. It is essential to establish general agreement on the laboratory's mission.***

One must ensure the mission is consistent with that of the parent organization. Also, the manager should determine how much flexibility exists for expanding the mission into new areas. As noted in Chapter 1, some organizations are very flexible, and some are quite firm in holding to the present mission.

### ***2. Continuous long-range planning is important.***

All laboratories have a planning function. A long-range plan is important to guide the preparations for future work. It should be the basis for the annual budget submission, which also serves as a short-range plan.

In the Army, the Office of the Chief Scientist oversees the preparation of the Army Science and Technology Master Plan. The focus is on implementing research programs already agreed upon rather than considering long-range opportunities. Successful long-range planning requires forecasting developments in research over, say, 25 years, and forecasting

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<sup>33</sup> These National laboratories address the responsibilities for measurements that fall under the Treaty of the Meter signed in 1875. Their work is overseen by the International Committee on Weights and Measures and its Bureau of Weights and Measures, with offices at the Bureau International des Poids et Mesures' laboratory in Paris, France.

likely capabilities needed by the warfighter over the same period. The result will represent the vision for the S&T program.

***3. The organization of the laboratory should be consistent with the management style of the director and should facilitate communication and cooperation within the laboratory.***

Many organizational changes are minor, affecting only small segments of the laboratory. Major reorganizations usually alter a laboratory's overall structure and affect everyone. Such full reorganizations should not occur too often. NBS/NIST saw only four major reorganizations in the first 90 years of its existence.

As noted in Chapter 3, laboratories are now tending to have flatter organizations with less hierarchy. The hope is that this structure will be more efficient in terms of internal communications.

***4. A highly competent staff is the most important factor in the success of a research laboratory.***

A laboratory must use all avenues of attracting and retaining excellent staff. Some options, such as post-doctoral appointments, are very effective in adding new staff. Mentoring is also important. Managers should make every effort to retain top employees.

***5. The director must be involved with all the staff and insist that subordinates stay close to the bench-level personnel.***

The director needs to take advantage of all expertise in the laboratory, including the director's senior associates and subject matter experts across the laboratory. Particularly useful advice is also available from non-managerial senior staff, known in the Army as STs or Senior/Technical Professionals.

The laboratory should have a discretionary director's fund to support new ideas proposed primarily from the staff. This fund can be as little as 3 percent of base funding up to as much as 10 percent (see Chapter 5).

***6. Outside experts should perform regular, formal, and external reviews of a laboratory's quality.***

An external group of experts should assess a laboratory's quality regularly. An external body, such as a contractor, should manage and conduct the assessment. Acknowledged, independent experts should perform this unbiased appraisal. Care should be taken to handle conflicts of interest. This review is hard to do in industry because so much of a laboratory's work is proprietary. Often, external consultants review specific portions of a laboratory's work.

## **APPENDIX A. THE RESEARCH LABORATORY—THEN AND NOW; SUGGESTIONS FOR THOSE ENTERING UPON AN R&D CAREER**

When I was an undergraduate major in chemistry in the late 1940s, we didn't do research or write an undergraduate thesis. Experimentation was closely specified in the various laboratory segments of the coursework. All of the bench work was hands-on synthesis and analysis using only the simplest of instrumentation, such as weighing and temperature measurements.

When I arrived in the research department in a division of the Monsanto Chemical Company in 1955, research experiments made use of X-ray crystallography, some spectroscopy, early versions of chromatography, high-temperature ovens and furnaces, automatic titration devices, and pH meters. We were initially at a remote site and, to obtain X-ray information, had to send samples halfway across the country to a company laboratory with that capability. Most of what we did was weighing, heating, dissolving, precipitating, extracting, and making titrations of various kinds. When I moved to a new laboratory facility at a new company headquarters, the instrumentation was consolidated. The laboratory had applied recently developed nuclear magnetic resonance (nmr) techniques using early, commercial nmr spectrometers to elucidate the structure of complex phosphorus compounds. This analytical tool became a standard experimental technique to complement the various X-ray and spectroscopic devices at our disposal. However, these machines were set up in separate laboratory modules and monitored by specialists. These folks trained users, kept the machines in operation, and did their own research. (Note: These practices were for chemical research laboratories. The situation would have been different for different disciplines.)

Research in those days was considered to be either in theory or in experiment; sometimes, research was simply observation, as in astronomy or biological taxonomy. The advent of the computer changed all of that. In the mid-1950s, Monsanto acquired an IBM 701 computer and made it available to the staff. However, the computer group generally did the programming, and the researcher merely provided the problem and some data. A select group of specialists—mathematicians, statisticians, and some engineers—programmed and operated the computer. The individual researcher designed and ran experiments and then took the data to the computer group. Later, the computer group sent a printout of results back to the researcher. Monsanto had also acquired a large analog computer useful in modeling process operations. I persuaded the chemical engineers at the analog machine to model a wet-process cement kiln (steady state) for use in a technical support program on which I was engaged. Once the kiln was modeled, we tried various input conditions to see if the postulated effect on performance could be realized. It could. They went on to produce a digital model of the time-dependent behavior of a kiln. This was my first encounter with modeling and simulation. The researcher generally did no programming and had no direct interface with the computer. Not until years later was remote access provided from terminals distributed throughout the company's laboratories. Then such use meant researchers either had to write their own programs (usually in Fortran) or had acquired programs from someone else. By the time I left in 1973, there were still no computers in the research lab modules.

This all changed rapidly. When I went to NBS in 1973, wave after wave of new developments were occurring in solid state devices and computers. First came the so-called minicomputers,

such as the DEC VAXs, that were set up in a few laboratories at NBS. Small groups of researchers used, operated, and maintained these minicomputers. Additional staff were not hired just to maintain and operate the computers. A number of these machines were installed for special applications, such as designing circuits for silicon chips and devices or modeling chemical reactions at the molecular level. Soon, the personal workstation and the personal computer (PC) were introduced.

At about this time, the staff in the computer institute developed NBSNET to provide access by wire around the campus. This was one of the first local area networks. NBS secretaries turned in their IBM Selectric typewriters for the early PCs. NBS standardized use of these computers so report text and other documents could be moved around the lab from one machine to another. In a parallel development, small computers began to be installed in experimental apparatus to monitor and control experiments. Vast amounts of data were easily collected and subsequently analyzed. Lab benches began to look like those in electronics or computer companies.

Ultimately, nearly all scientific equipment became digitized, providing controlled introduction of reactants, controlled changes in conditions, and automated measurement of results. The results were often analyzed during the experiment, and answers were printed out. Thus, one could analyze something with a mass spectrometer, and the machine would compare the output to tables of data stored in its computer and then print out the most likely compound. The laboratories became automated. Researchers had to learn a great deal about these machines and their nuances and less about manipulating experimental materials.

When the power of main computers reached a certain level, a new third branch of research was recognized—namely, computer modeling and simulation. With the supercomputer, a physical and chemical model could be built for various problems. Once the model's performance was verified by comparison with actual experiments, the computer model could be used to make many runs to test the sensitivity of the phenomenon being studied to changes in parameters. For some problems where running many full-scale experiments would be too costly, the computer models enabled much broader and more informative studies. Today, many such models can be developed and run on powerful desktop computers. But for the most complex modeling, the largest and fastest supercomputers are still, and probably always will be, needed.<sup>34</sup>

In the 1940s, 1950s, and even into the 1960s, the research chemist's bench top consisted mostly of reagents on shelves or inside a fume hood, lots of lab glassware, a few stirrers and hotplates, and an occasional pH meter or automatic titrimeter. One of the regular tasks, for professionals as well as lab assistants, was to carefully wash and rinse the glassware, sometimes cleaning it first with baths of hot, concentrated acids. Residues of experiments were almost always flushed down the sink, relying on a neutralizing basin outside the building. No more. Today, laboratory waste is classified as hazardous, placed in containers, and hauled away by special contractors to special disposal sites.

Today, when walking through a chemistry laboratory, one may not see many lab modules with reagents on shelves and glassware on the bench. Now, a chemical lab or a physical chemistry lab

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<sup>34</sup> A recent NRC study made this point. See *The Potential Impact of High-End Capability Computing on Four Illustrative Fields of Science and Engineering*, Division on Engineering and Physical Sciences and Division on Earth and Life Sciences, NRC of the National Academies, National Academies Press, Washington, DC, 2008.

often consists of bench-top devices that may each cost \$1 million or more. These may be analytical instruments, devices for synthesizing systems such as molecular beam epitaxy for microchip research, and systems for observing behavior. These devices may operate at extreme pressure (or vacuum) and temperature (very low or very high). I have seen individual research lab modules filled to bursting with machines operating at very high vacuums and ultralow temperatures—not just one but several in a module. In an NBS laboratory that studies the behavior of trapped ions at near absolute zero temperatures, it was difficult to move around because the space was so full of apparatus. Some labs use high vacuum systems to study the behavior of a few atoms or molecules moving about on substrate surfaces. Lasers are ubiquitous and used for measuring lengths, defining time and frequency, burning patterns into surfaces, and on and on. An interesting phenomenon is that if an experiment originally requiring a roomful of apparatus were to become of commercial interest, a company would eventually find a way to miniaturize the system , even to make it portable. This happened with mass spectrometers and other tools used in the field to make measurements.

Some experimental systems require special facilities. A research reactor, for example, requires a confinement chamber for the reactor itself and an associated instrument hall where beams from the reactor are incorporated into particular experimental setups. The reactor at the NIST Center for Neutron Research, for instance, has nine instrument stations in the confinement chamber and an additional fourteen stations in an adjacent hall where beams of neutrons are guided to experimental stations. Each station performs a particular experimental task. A continuous stream of guests from NIST programs and other private and public research organizations use these stations for a few days at a time. A synchrotron for providing beams of well-characterized far ultraviolet and X-ray radiation requires special support services. Several “light sources” of this nature exist around the world as designated user facilities. Everyday scientific and engineering research has become an expensive and often very complicated endeavor—far more than 50 years ago.

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In thinking back, I can determine some factors that are important for a fulfilling career in R&D. As a young person just thinking about such a career, good preparation requires a few considerations. I decided to become a chemist and majored in chemistry in college. In addition to courses in chemistry, I took 2 years of calculus and 1 year of physics. That was clearly not enough.

I finished work on my bachelor's degree, put in 2 years in the U.S. Army, and then went to work in the research department of a division of the Monsanto Chemical Company. I quickly learned that an AB in chemistry wasn't enough for a career in research. So I took graduate courses and did my thesis, leading to a PhD in physical chemistry. My PhD provided a background in thermodynamics, statistical mechanics, polymer science, quantum chemistry (which didn't help much when quantum computing came along), and other courses I felt I needed. But I still didn't take enough physics and math.

I found, after taking positions in research management at NBS (later NIST) and later at ARL, that I was overseeing work in physics, material science, and engineering, as well as managing the computing enterprise. For example, I needed to understand the engineer's approach, particularly for open systems. Chemists largely deal with closed systems in equilibrium. Engineers deal with

open systems involving heat and mass transfer. These systems require a different way of addressing problems and a different mathematical approach. I had no formal training in these areas and had to study the subject matter on my own. The same was true in physics. At NIST, I had to oversee some very fundamental research in physics. I learned most of it through many briefings from the scientists. Some of this I filled in by independently studying textbooks on physics, such as Richard Feynman's Lectures in Physics and the Berkeley Course in Physics. These were helpful, but I would have benefited more from classroom study. I strongly urge people entering scientific work to take as much math and physics as possible—they underlie nearly all of the physical and biological sciences.

In addition, before starting serious study for a research career, some summer work in a laboratory would be helpful in understanding what the work entails and in deciding whether to go to graduate school. I believe a career in research requires a PhD in a relevant discipline. I didn't go to graduate school until I was working full-time in a laboratory and had already started my family. The burden of two jobs, a family, classwork, and thesis research was exhausting; I would not advise anyone do it this way.

Once at work in the laboratory, I recommend that one seek out a mentor or sponsor—someone you respect and who can get things done in the organization. This more senior person may provide coaching in specific challenges to you or may offer more general philosophical advice. I found such a person at Monsanto. I never worked for him, but I learned from his example and received the career guidance I needed. When we were talking about the future, he suggested the following exercise: Write down the 10 most important things you want to accomplish, and then write down the 10 things you are willing to give up to achieve those accomplishments. I tried it and couldn't get beyond about five items in each category. This analytical approach led to my return to graduate school and later to my leaving the company and joining the U.S. Government at NBS. I've never regretted it.

Another thing I learned from this individual is to “always leave tracks.” By this, he meant writing and speaking before audiences and being active in professional activities outside one's immediate environment. He was a prodigious contributor to scientific literature, including a great many scientific papers and books and two treatises on the chemistry and uses of phosphorus and its compounds. He was known as perhaps the world's expert in his field. He went on to serve as a senior professor of chemistry at a leading university. By leaving tracks, one establishes a reputation both within one's own organization and within the community at large. When it comes time to make a change, one's external reputation is a critical factor in employability.

When deciding how to publish findings—internal report or outside refereed publication—the people I respected most usually opted for external publication, assuming the company would clear it. I published both internal reports and external refereed articles, and I authored or co-authored three books. My move to NBS came as a result of a monograph (book) I wrote on the chemistry and uses of fire retardants. It was one of the first treatises on this subject and received considerable attention. Just after its publication, NBS was looking into its work on fire safety standards as a result of congressional interest. NBS requested a study by NRC, and NRC created an ad hoc committee for this purpose. The committee had a number of academic experts in physical modeling of combustion phenomena and needed someone to represent chemistry. My book caused NRC to put me on the committee. My service led to NBS recruiting me to come to

NBS to manage a new, consolidated NBS Center for Fire Research. I decided to do it for little while; I stayed for 20 years.

Another lesson I learned early on was the value of taking a fundamental scientific approach to what would appear to some as a mere technical service. The best scientists and engineers are those who look deeply into a problem—whether it arises in new research, the production department, or the sales department. These scientists and engineers apply their knowledge of basic science and engineering to find a solution. Often because of this approach, they can contribute to the community at large by publishing non-proprietary results. This is a lesson I have observed in practice throughout my many years in R&D. The finest chemical process engineer I ever met always began a problem by developing the thermodynamics, kinetics, and equations for heat and mass flows for the operations in question. When my colleagues agreed to model the wet-process cement kilns I worked with, they performed what we now call physics-based modeling. The modelers required thermodynamic and kinetics information, along with the characteristics of the kiln and the combustor, to enter into the analog computer—and later the digital computer.

I later expanded this lesson on the importance of taking a fundamental approach to research work to the work of a group, division, or entire laboratory. I believe an effective laboratory must have a strong component of basic research on which to build mission-oriented work. Indeed, I think about 15 percent of a laboratory's work should be in this category. It turns out, many others agree with this view.